Chapter

Modeling the Environment with Remote Sensing and GIS: Applied Case Studies from Diverse Locations of the United Arab Emirates (UAE)

Salem Issa and Nazmi Saleous

Abstract

Maintaining a healthy and sustainable environment is of paramount importance for human well-being and economic activity. Hence, environment protection, requiring continuous and reliable monitoring, has become a major mandate at various levels of government. There is a direct link between the availability of information about environmentally endangered areas and sound decision-making for effective and sustainable management. While remote sensing allows acquiring relevant information on a regular and repetitive basis even in areas where accessibility is limited, geographic information systems (GIS) provide unique tools for storing, processing, and integrating this information with other sources enabling the development of spatial models that help identify and characterize environmentally endangered areas. In this chapter, we will discuss how GIS-based modeling is applied for solving diverse environmental problems using case studies from United Arab Emirates.

Keywords: environment, remote sensing, GIS, modeling, urban growth

1. Introduction

Although deserts or arid lands typically do not have a large number of inhabitants, they are often the loci of economic and cultural activity. For example, the oil-producing nations of the Middle East are all found within a single arid region. Furthermore, deserts tend to be fragile ecosystems, requiring little in the way of perturbations in order to cause tremendous changes in the landscape [1, 2]. The size, remoteness, and harsh nature of many of the world's deserts make it difficult and expensive to map or monitor these landscapes or to aid planning for and management of renewable natural resources. The situation exacerbates in developing countries where lack of accurate maps and the need for rapid and relatively accurate mapping techniques are urgent; this is becoming challenging if we know the dimension of large-scale engineering projects being implemented, particularly in the wealthy Gulf States [3, 4].

Remote sensing and GIS are promising new-time and cost-effective techniques to image remote arid and hyperarid lands. With the use of ancillary field data and the calibration of remote sensing inputs, data integration within a GIS can enhance the extraction of information from satellite imagery and has led to a synergistic approach in spatial data handling and modeling [5–7], hence improving the accuracy of a variety of outputs [8, 9].

In this chapter, we will expose the power and benefit of integrating remote sensing and geographic information systems to model our environment through various case studies applied to the arid/hyper arid environment of the United Arab Emirates. Four case studies are introduced and discussed in Section 3 namely:

- Characterization of Al Ain city urban growth using multi-temporal remote sensing data and GIS [10].
- Assessing landfill locations for waste management for the city of Abu Dhabi using GIS [11].
- Mapping sand dune fields in Abu Dhabi Emirate over the period 1992–2013 [12].
- GIS-based wind farm site selection model offshore Abu Dhabi Emirate, UAE [13].

2. Research approach

Remote sensing and GIS are incorporated into environmental modeling for addressing environmental issues and problems. The core of this approach is to use the power embedded in these geospatial techniques to develop and implement a GIS project. Remote sensing here is treated as the science, technology, and techniques used to acquire the wanted data concerning the study area, processing those data, extracting relevant information about the studied area, and exporting the resulting file into a geodatabase.

A typical GIS project includes (1) stating the problem; (2) defining the study area; (3) acquiring, preparing, and automating the data; (4) processing the data; (5) building the geodatabase; (6) analyzing; and (7) visualizing, mapping, and report writing.

2.1 Stating the problem

The first step of implementing a GIS project is to state the problem and identify the objective of the analysis. The following questions need be addressed: What is the problem to solve? How is it solved now? Are there alternate ways to solve it using a GIS? What are the final products of the project—reports, working maps, and presentation-quality maps? Will the data be used for other purposes? What are the requirements for these? This step is important because the answers to these questions determine the scope of the project as well as how you implement the analysis.

2.2 Defining the study area

This step delineates a narrowed boundary of an area of interest. The information from *Step* 2.1 tells us about the proper location where the problem occurred and addresses the possible questions and answers under interest.

GIS possesses many and convenient ways for demarkation of a project's boundary. ERDAS IMAGINE® and ArcGIS®, worldwide used GIS software packages, allow users to work with geographic information data by inputting and manipulating map layers in a comprehensive manner. In this chapter, we use ERDAS Imagine 2014 and ArcGIS 10.6 for implementing all remote sensing and GIS processes.

2.3 Acquiring the data

Before locating and acquiring the needed data, a list of criteria should have been set to address the identified objectives of the problem to be solved in the study area.

Consider the following two real-world examples:

Example 1: Landfill Locations for Waste Management of the City of Abu Dhabi Using GIS (**Table 4**) and,

Example 2: GIS-based wind farm site selection model offshore Abu Dhabi Emirate, UAE (**Tables 7** and **8**).

Furthermore, the methodology needs to be analyzed to establish what kind of data is needed. The most important question that needs to be answered is Why do I need these data? If the data are truly needed, then this question is easily answered. If not, then the data are most likely not necessary to solve the problem.

To be able to work with data in GIS, you need to understand the nature and procedural steps of working with GIS data such as dataset formats, dataset attributes, dataset completeness, coordinate systems, and dataset sources (see **Tables 1** and **5**).

Data type	Primary/ secondary	Date	Resolution/ accuracy	Source
Landsat MSS	Primary	29 January 1972	57 m	UAEU
Landsat TM	Primary	28 august 1990	28.5 m	UAEU
Landsat ETM+	Primary	23 March 2000	15 and 30 m	UAEU
Aerial photos	Secondary	1976 and 1983	1:5000 and 1:50,000	Al Ain Town Planning and Surveying Sector
Al Ain land use map	Secondary	2000	30 m	UAEU
IKONOS	Secondary	2000 and 2006	1 m	(TPSS)
Master Plan of the Al Ain region	Secondary	1986–2000 and 2000–2015	—	(TPSS)
Al Ain administrative boundary map	Primary	2008	—	(TPSS)
Demographic data	Secondary	1989, 1995, 2001, and 2005	—	(TPSS) & UAEU

Table 1.
List of primary and secondary data used in the research.

2.4 Processing and preparing the data

Remote sensing data need to be prepared before being used for information extraction. This operation is made up of two main sub-processes: *pre-processing* and *processing*.

Pre-processing: involves data restoration which means data correction. This involves radiometric, atmospheric, and geometric correction and map projection.

Processing: involves data enhancement, data classification, data validation, and data export to GIS format.

In a GIS project, data processed and exported from remote sensing will serve as one input into the GIS database. GIS has a database management system component to support the proper management of both spatial and attribute data. It also enables convenient linking and relating of various data records by their locations on a common coordinate system. Some common tasks should be executed during the data processing and preparing step; these are as follows:

Re-defining and re-projecting data: The purpose is to define or/and to convert a particular layer of data from one coordinate system to another. Working with GIS involves more than one GIS layer; therefore, acquired datasets may contain different projections. Different data projections lead to distortion of data and inaccuracy in the analysis.

Conversion between raster and vector data models: File formats can also be varied in the forms of raster (*for example*, data derived from the remote sensing process) or vector (shapefile or feature class). Feature classes and shapefiles usually come embedded with attribute data, which allow the user to easily select and manipulate the information of interest. Therefore, converting a raster file to vector enables the user to intersect other available vector data.

Reclassification: To perform certain analysis in most cases, data need to be reclassified beforehand. Reclassification is a local operation that performs raster data analysis on a point-by-point or cell-by-cell basis. Reclassification, also commonly referred to as recoding, will reduce the number of classes you are using in the analysis, thus facilitating the analysis process and resulting in more accurate results. There are different reclassification methods such as binary masking, classification reduction, classification ranking, and changing measurement scales.

Data querying: Data querying in GIS involves both query by attribute and query by location. Both use certain conditions that apply to either the spatial or the non-spatial component of the analyzed data. The purpose is to extract desired features based on their location, attributes, or both for analysis. This can be done through conditional statement imposed in location or/and attribute data table to select only specific information of interest.

Data export: To make a temporary layer permanent in a current geodatabase, data resulted from steps such as that of the above need to be exported and saved in a working geodatabase or a current working space for further or future work.

2.5 Building the geodatabase

Creating the database for a GIS project will involve assembling the existing data, reviewing it, and then preparing the data for analysis. Some of the data will be usable as such; other layers will need additional processing. Sometimes you need to extract data from a possibly larger original source file. Reduction of the size of datasets and their consolidation accelerate the ensuing data processing and management. Typically, data acquired may exist in various forms and shapes, e.g. different coordinate systems and file formats. It is necessary to prepare and consolidate all datasets into a commonly operable form. GIS has a database management system

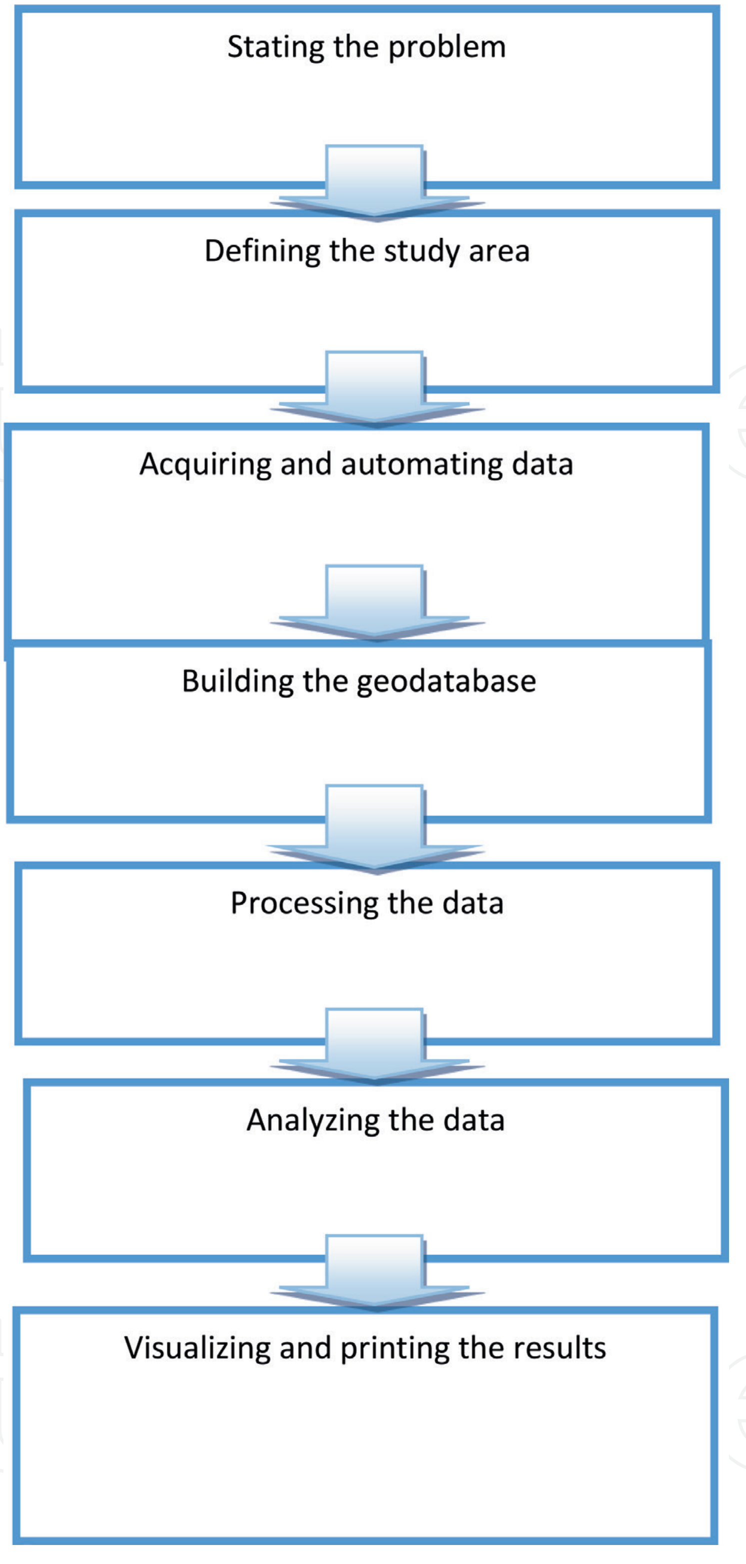

Figure 1.
Diagram of a typical GIS project: (1) stating the problem; (2) defining the study area; (3) acquiring, preparing, and automating the data; (4) processing the data; (5) building the geodatabase; (6) analyzing; and (7) visualizing, mapping, and report writing.

component to support the proper management of both spatial and attribute data. It also enables convenient linking and relating of various data records by their locations on a common coordinate system.

2.6 Analyzing the data

GIS analysis covers a wide variety of operations that you can do with a geographic information system. These range from simple display of features to complex, multistep analytical models. Perhaps the simplest form of GIS analysis is presenting the geographic distribution of data. This is conceptually the same as sticking pins in a wall map, a simple but powerful method of detecting patterns. A second type of GIS analysis is querying, or selecting from, the database. Queries let you identify and focus on a specific set of features. There are two types of GIS queries, *attribute* queries (find features based on their attributes) and *location* queries (find features based on where they are). A third type of GIS analysis is finding what is near a feature (buffering); a powerful function of GIS analysis is that the output of one procedure can be used in another. Here, the buffered zone can be used in an attribute query. A fourth type of GIS analysis is overlaying different layers of features. You can create new information when you overlay one set of features with another. There are several types of overlay operations, but all involve joining two existing sets of features into a single new set of features. Finally, all these techniques and many others are combined into a more complex GIS analysis, thus creating detailed models of the world to solve complicated problems. It is possible to repeat an analysis using slightly different parameters several times and compare the results. This can allow you to refine your analysis techniques.

2.7 Visualizing and printing the results

The last step in a GIS project is to present and communicate the results of your analysis. Your final product should effectively communicate your findings to your audience. The results of a GIS analysis can best be shown on a map. Nevertheless, they can also be disseminated through charts, reports, or videos and animated maps. You can print charts and reports separately, embed them in documents created by other applications, or place them on your map.

All the above steps are summarized in **Figure 1**.

3. Case studies

3.1 Characterization of Al Ain city urban growth using multi-temporal remote sensing data and GIS

The population of the UAE rose exponentially from around 86,000 in 1961 to more than 4 million in 2005. This has resulted in enormously rapid emplacement of a modern infrastructure, including an extensive highway and road networks, residential areas, shopping malls, golf courses, airports, and industrial facilities. The scale of such ambitious developments (often referred to as 'mega-projects') has been amazing and unmatched on a world scale.

In this case study, an attempt has been undertaken to map 'urban areas' in Al Ain city from large and medium-scale Landsat imageries in three different dates spanning the period 1972–2000 and to characterize the urban growth of the city using three different approaches: qualitative (using milestone change trajectories in the city), quantitative (using spatial metrics), and GIS overlay analysis.

3.1.1 Requirements for characterizing urban growth using remote sensing data

Capturing and analyzing the landscape change of the UAE have become key components to planners and policy makers in order to identify causes and assess the consequences of these changes on the future development of the society. Here rises the challenge of finding an effective way of measuring and documenting this change, sometimes very rapid, for a sustainable development that augments the people welfare while preserving the environment. Measurement and analysis of urban growth using remote sensing and geographic information system (GIS) techniques have seen very limited application examples in the UAE.

The study area is located between 55°28′ E to 55°53′ E longitudes and 24°03′ N to 24°22′ N latitudes (**Figure 2**). Al Ain is situated 150 km from Abu Dhabi capital city and 160 km from Dubai on the feet of Hafeet Mountain to the south and bordering Oman international boundaries to the east. The city is a perfect example of a small desert oasis with primitive society and limited resources to transform into a well-developed large city with an urban center hosting more than half a million inhabitants within a quarter of a century, making it an ideal example for urban growth studies using new remote sensing and GIS techniques in the region.

3.1.1.1 Datasets

A set of primary and secondary data is used in the research. Three Landsat satellite images from 1972, 1990, and 2000 (i. e., MSS1972, TM1990, and ETM + 2000) are processed and analyzed using ERDAS Imagine for the extraction of LULC classes in the three dates. Large-scale historical aerial photographs besides other ancillary data are used as reference data for accuracy assessment as well as in the geo-database building for further spatial analysis in GIS (**Table 1**). All images are atmospherically calibrated and geometrically rectified to a common Universal Transverse Mercator (UTM) coordinate system, zone 40, and the WGS84 Datum.

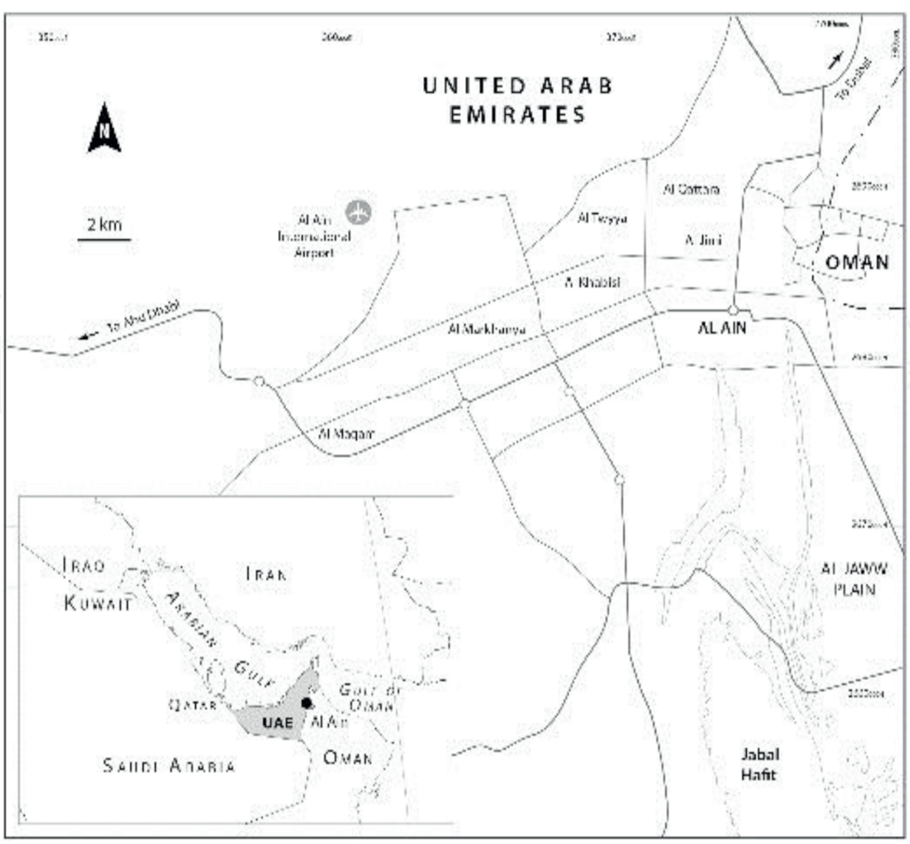

Figure 2.
Study area.

3.1.2 GIS project implementation for characterization of Al Ain urban growth

3.1.2.1 Classification schema

A hybrid of unsupervised and supervised classification schema is used. First unsupervised classification is carried out using the ISODATA algorithm. A number of iterations of 67, 80, and 60 for MSS, TM, and ETM+ are reached respectively with the convergence value at 0.990. The maximum likelihood algorithm with training sites carefully selected from the unsupervised classification results is used to run the supervised classification. Furthermore, the classified images were filtered using a 3 × 3 majority filter to remove speckles and to smooth the resulting images and decrease analytical errors.

The following are six classes representing most land cover types of the study area:

- Urban (built-up including roads and buildings)
- Vegetation (oases, farms, and parks)
- Sand and gravel (dark soils)
- Sand dunes (bright sand)
- Limestone
- Water bodies and shadow

3.1.2.2 Urban class extraction

Urban class is defined in this case as 'all manmade features including buildings, roads, and pavements in addition to vegetation covered areas such as oases, farms, parks, and farmed areas within the city boundary'. To extract urban areas, a bitmap is created to include urban and non-urban only.

3.1.2.3 Spatial metrics

The application of a number of spatial metrics is used to characterize the urban growth of the city. As such, the following spatial metrics are used:

- Land consumption rate (LCR)
- Land absorption coefficient (LAC)
- Annual urban growth rate (AGR)
- The percentage of built-up land (PLAND_U)

3.1.2.4 Change analysis techniques

The post-classification comparison approach is used based on comparing separately the produced classified LULC maps (1972, 1990, and 2000) in order to identify the change in the LULC classes and provide descriptive information about the nature of change that occurred in different dates. Spatial metrics and GIS overlay analysis are used to characterize changes in the urban area class. A total of eight instances of urban change trajectories are produced (**Figure 3**) [8].

3.1.2.5 Results

3.1.2.5.1 Urban class extraction

Urban areas were extracted using a semi-automatic method including manual editing of boundaries of certain classes based on authors' familiarity with the study area. A value of 1 was assigned to classes that fall in the urban category while a value of 0 was given to all other classes (**Table 2**).

3.1.2.5.2 Spatial metrics calculation

Results of the spatial metrics calculation are shown in **Table 3**.

3.1.2.5.3 Change detection between 1972, 1990, and 2000

Change detection analysis across 1972, 1990, and 2000 was conducted using the post-classification comparison method. The LULC classification results are presented in **Table 1**. The GIS overlay analysis was also applied on the LULC maps, which allowed the creation of 216 (=6^3) possible combinations of classes over the

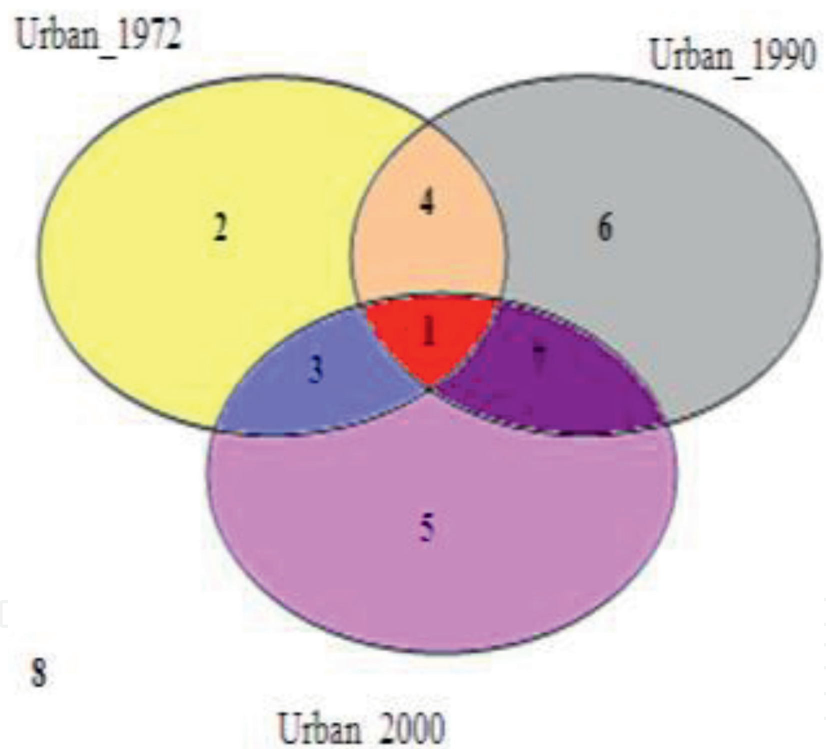

Figure 3.
Instances of urban change trajectories 72–2000.

LULC classes	1972		1990		2000	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Urban areas	4107.00	5.33	13,965.00	18.14	20,160.00	26.18
Others	72,893.00	94.67	63,035.00	81.86	56,840.00	73.82
Total	77,000	100.00	77,000	100.00	77,000	100.00

Table 2.
Areas (hectare) of urban areas.

study period, hence producing 216 different from-to-to change maps (not shown here). As our main concern was on the change characteristics of urban areas, a map was created using ArcGIS displaying the eight different instances of urban change trajectories throughout the study period (**Figure 4**).

In conclusion, it was found that neither Hafeet Mountain nor the sand dunes have ever formed a barrier to urban growth and will probably not do so in the future. Furthermore, it seems that in the short-term, the city will not witness urban expansion across the sand dunes for reasons explained above. However, it is thought that policy makers and planners will be forced to review their decisions to reverse the expansion from being horizontal, which was the case for the last forty years, to become vertical in order to minimize the necessary expenses of reclaiming more lands from sand dunes to urban areas, and to avoid more investments in kilometers of water pipes, electricity lines, and other infrastructures.

Year	LCR	PLAND_U (%)	Period	AGR (%)
1972	1.52	5.33	1972–1990	0.67
1990	0.43	18.14	1990–2000	0.73
2000	0.29	26.18		

Table 3.
Spatial metrics used for urban growth characterization.

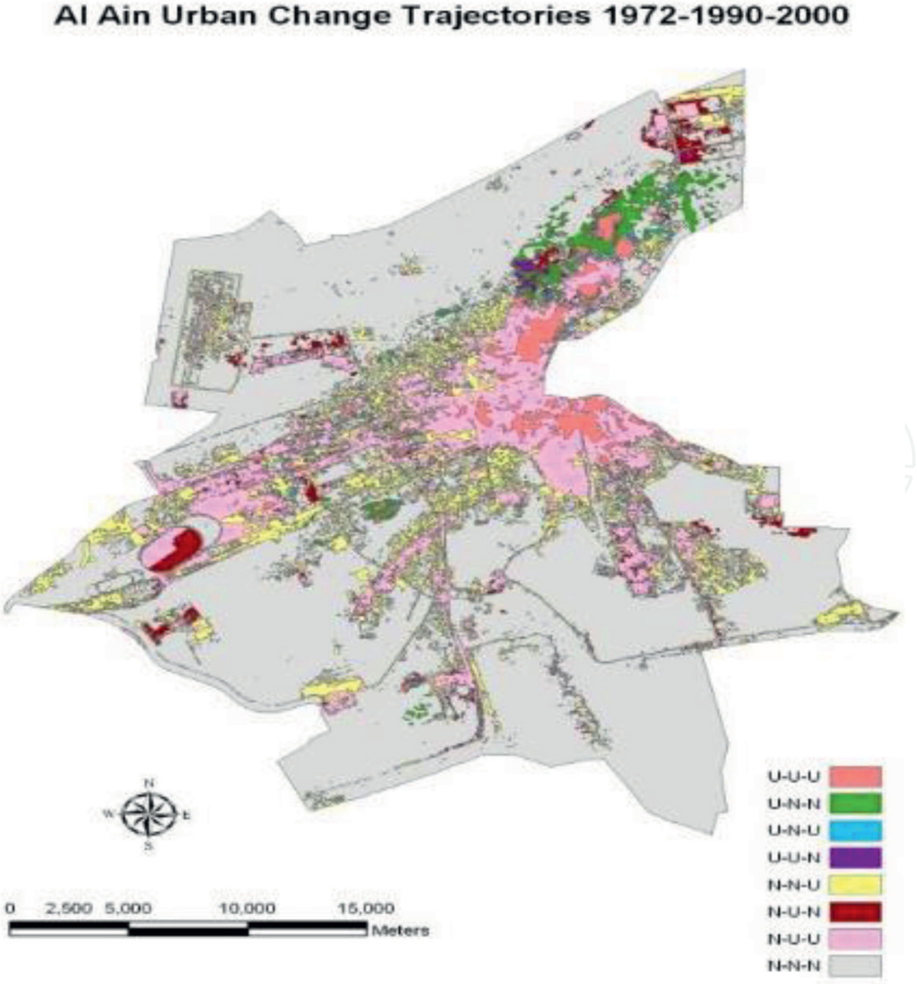

Figure 4.
Al Ain Urban area trajectory maps in 1972, 1990, and 2000. U, urban; N: non-urban.

3.2 Assessing landfill locations for waste management for the city of Abu Dhabi using GIS

The location of waste treatment and disposal facilities often has an impact on property values owing to noise, dust, pollution, unsightliness, and negative stigma. Hence, proper waste management practices need to be adopted to minimize the risks to human health and the environment.

3.2.1 Requirements for landfill location

A landfill must be situated and designed so as to meet the necessary conditions for preventing pollution of the soil, ground, and surface water as well as ensuring efficient collection of leachate. Similarly, a landfill site should be kept as far away from densely populated areas as possible, to reduce the impact of pollution on public health. At the same time, the landfill site should be placed as close as possible to existing roads to reduce costs of road development, transportation, and waste collection. Likewise, uneven or steep terrain is not appropriate for hosting landfills. As a result of an extensive literature review, local regulations, and expertise, a set of 19 criteria of an appropriate landfill site was identified and grouped into five parameters (**Table 4**).

3.2.2 GIS project implementation

The study area of the actual study is delimited by the administrative boundary of Abu Dhabi City Municipality. Datasets representing the set of 19 criteria identified in **Table 4** were collected from Abu Dhabi Municipality, the Environmental Agency of Abu Dhabi, Statistics Center of Abu Dhabi, and the National Center of Meteorology and Seismology. These datasets were clipped using the study area boundary, converted to a common spatial frame (UTM coordinate system, WGS84 datum, and Zone 40N), and added into a geodatabase for analysis.

The site selection process adopted a multi-criteria evaluation (MCE) approach that produces a suitability map from the criteria listed in **Table 4**. Given the varying importance of the parameters used in the selection process, they are assigned different weights as illustrated in **Table 4**. The overall suitability score (S) is then calculated based on the simple additive weighting (SAW) method as per Eq. (1).

$$S = \Sigma w_i \times x_i \tag{1}$$

where S is suitability, w_i is the relative weight of parameter i, and x_i is the rank (score) of parameter i. x_i is calculated as the sum of ranks of all the attributes belonging to parameter i and then normalized to the range 1–10 with 1 indicating the most favorable condition. The suitability value for each parameter was reclassified into four classes: Highly suitable (1–2), Suitable (3–5), Moderately suitable (6–7), and Unsuitable (8–10). The final suitability (S), calculated using Eq. (1) and reclassified into the four pre-defined classes, is shown in **Figure 5**. The final results indicate that 41% of the study area is considered as highly suitable for siting a landfill. Only 27% of the study area is unsuitable mostly due to proximity to restricted areas and oil fields.

The created suitability map can be used to select candidate locations for a new landfill site from available parcels that fall within the most suitable regions, such as the seven sites shown in **Figure 5**, prior to evaluating their environmental impact in order to help in the selection process. Furthermore, the model was used to examine and evaluate the existing "Al Dhafra Landfill" shown in **Figure 5**. It was concluded that this particular site falls within the unsuitable zone, owing to its proximity to oil concession areas.

Parameter	Weight	Layer name	Classification	Ranking
Environment	30%	Hydrology	<500 m	10
			>500 m	1
		Groundwater	<5 m	10
			5–15 m	5
			>15 m	1
		Geology	Sabkha, Eolian	1
			Other	10
		Slope	Slope: >15%	10
			5–15%	1
			<5%	5
		Shoreline	<500 m	10
			>500 m	1
		Vegetation	<200 m	10
			>200 m	1
Socio-economic criteria	30%	Roads	<1 km	10
			1–5 km	5
			5–10 km	1
			>10 km	10
		Built-up area	<1 km	10
			1–5 km	5
			5–10 km	1
			>10 km	10
		Land use	Residential < 2000 m	10
			>2000 m	1
			Industrial <200 m	10
			>200 m	1
			Other < 200 m	10
			>200 m	1
		Utilities	<500 m	10
			>500 m	1
		Population density	<2000 m from densely populated areas	10
			>2000 m from densely populated areas	1
Climatological criteria	10%	Wind speed	High	10
			Low	1
		Rainfall	High	10
			Low	1
		Temperature	High	1
			Low	10

Parameter	Weight	Layer name	Classification	Ranking
Restricted areas	20%	Airports	<3 km	10
			>3 km	1
		Military area	<3 km	10
			>3 km	1
		Oilfields	<3 km	10
			>3 km	1
		Protected areas	<500 m	10
			>500 m	1
Political criteria	10%	Admin boundary	<1000 m	10
			>1000 m	1

Table 4.
Landfill site selection criteria with weights and ranks.

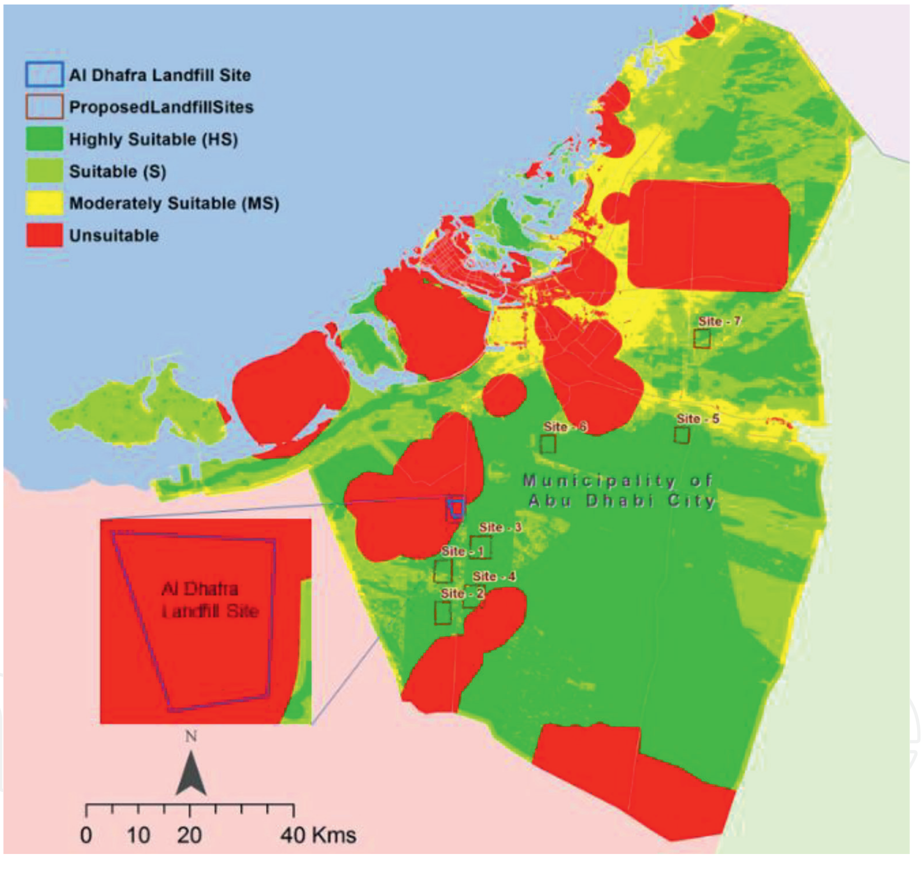

Figure 5.
The final landfill suitability map with the location of existing Al Dhafra landfill site and of potential sites for a new landfill (sites 1–7).

3.3 Mapping sand dune fields in Abu Dhabi Emirate over the period 1992–2013

The UAE has witnessed rapid economic growth since the discovery of oil in 1968. As a result, major urbanization and farming projects have been undertaken throughout the country including in the heart of the sand sea. Sand dunes and their movements present a serious threat to the country's urban centers as well as its infrastructure. This study focuses on the mapping of sand dune fields and assessing their changes over the period 1992–2013 in the UAE using Landsat imagery.

Availability of similar spatial and spectral characteristics of the Landsat TM and ETM+ sensors during the study period ensured the provision of consistent reliable imagery used in the study.

3.3.1 Requirements for mapping sand dune fields

Optical sensors have proven very useful in detecting sand over large areas. In particular, the use of discrete bands of multispectral sensors enables reliably to distinguish between sand and other land covers. Since the ultimate goal is to study changes in the sand cover extent, it is important that imagery used to map each representative period be acquired at anniversary dates.

In this study, we develop an approach to detect and map sand fields using Landsat imagery collected in three different years: 1992, 2002, and 2013. This approach is used to create land cover and sand/non-sand maps over the study area for the three different dates. We assess their accuracy using higher resolution imagery and store them in vector format for use in change detection studies. The study area encompasses the whole Emirate of Abu Dhabi extending over 67,000 km^2. It is characterized by a harsh climate where temperatures reach 48°C and humidity ranges between 80 and 90% in summer.

Six Landsat scenes that fall in different zones of the UTM coordinate system were used. It is necessary to convert the scenes to a unique coordinate system prior to creating a mosaic covering the study area and clipping the needed section. To delineate sand using a multispectral classification approach, a set of training and validation sites is needed. Higher resolution imagery from SPOT, Rapid Eye, and IKONOS is used in identifying and selecting these sites.

3.3.2 GIS project implementation

The approach used in this study is summarized in **Figure 6**. The scenes are mosaicked, referenced to a common frame, and clipped for each of the study periods. Only the reflective bands available on TM and ETM+ sensor and their counterpart on OLI are stored for use in processing. The datasets collected for use in the project are summarized in **Table 5**.

The core component of the processing consists in performing a supervised classification of the multi-temporal Landsat data. As a precursor, a classification scheme that includes important land cover classes present in the study area is developed based on spectral clustering of input datasets and familiarity with the study area. The final scheme includes the following classes: water, vegetation, sand, wet soil, intertidal, and bedrock. Different configurations of the processing flow showed that the overall accuracy of the classification increased if the vegetation class was extracted first using the soil adjusted vegetation index (SAVI). One hundred and forty two training sites selected randomly across the remaining classes are then used in the supervised classification process.

The resultant classified maps were reclassified into a binary sand/no sand map, vectorized, and exported to GIS. **Figure 7** shows the resulting land cover and sand/no sand maps obtained for the 3 dates. Accuracy assessment of the land cover maps was performed using a set of 94 assessment sites selected with the help of higher resolution imagery. The results indicated that the overall accuracy of the classification was 87% for the 1992 map, 89% for the 2002 map, and 91% for the 2013 map. However, sand class alone was mapped with a higher accuracy for all 3 years. **Table 6** summarizes the size of each one of the classes for the 3 time

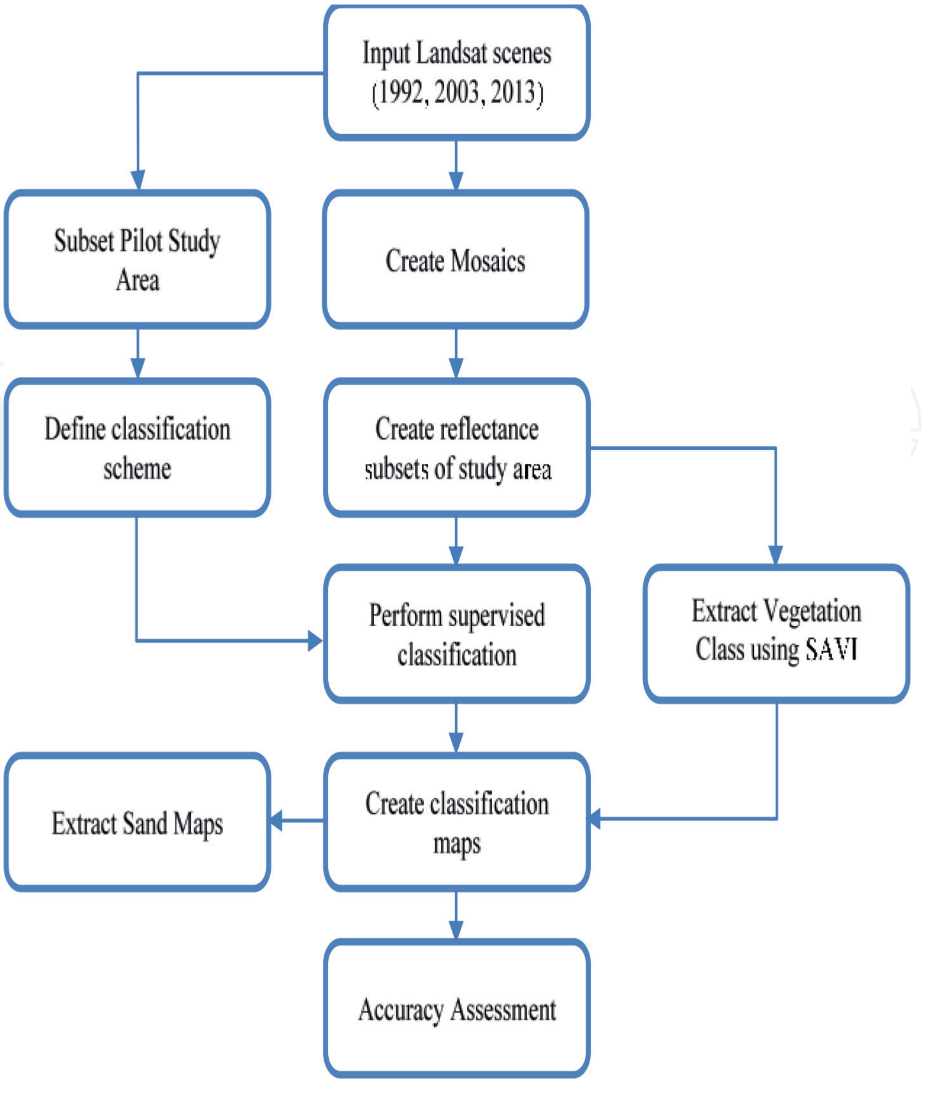

Figure 6.
Sand mapping methodology flowchart.

Data type	Date	Spatial resolution	Spectral characteristics	Purpose
Landsat 8 OLI	August 2013	30 m	Reflective bands	Classification
Landsat 7 ETM+	July 2002	30 m	Reflective bands	Classification
Landsat 4 TM	June 1992	30 m	Reflective bands	Classification
Rapid Eye	2013	5 m	RGB	Accuracy assessment
IKONOS	2003	1 m	Panchromatic	Accuracy assessment
SPOT panchromatic	1986	10 m	Panchromatic	Accuracy assessment
Abu Dhabi Emirate boundary shapefile	2013	—	Vector	Delimit study area

Table 5.
Datasets used in the study.

periods. It highlights the changes in the size of the sand class that can be attributed to different factors including sand encroachment, urban growth, establishment of farms, and dredging.

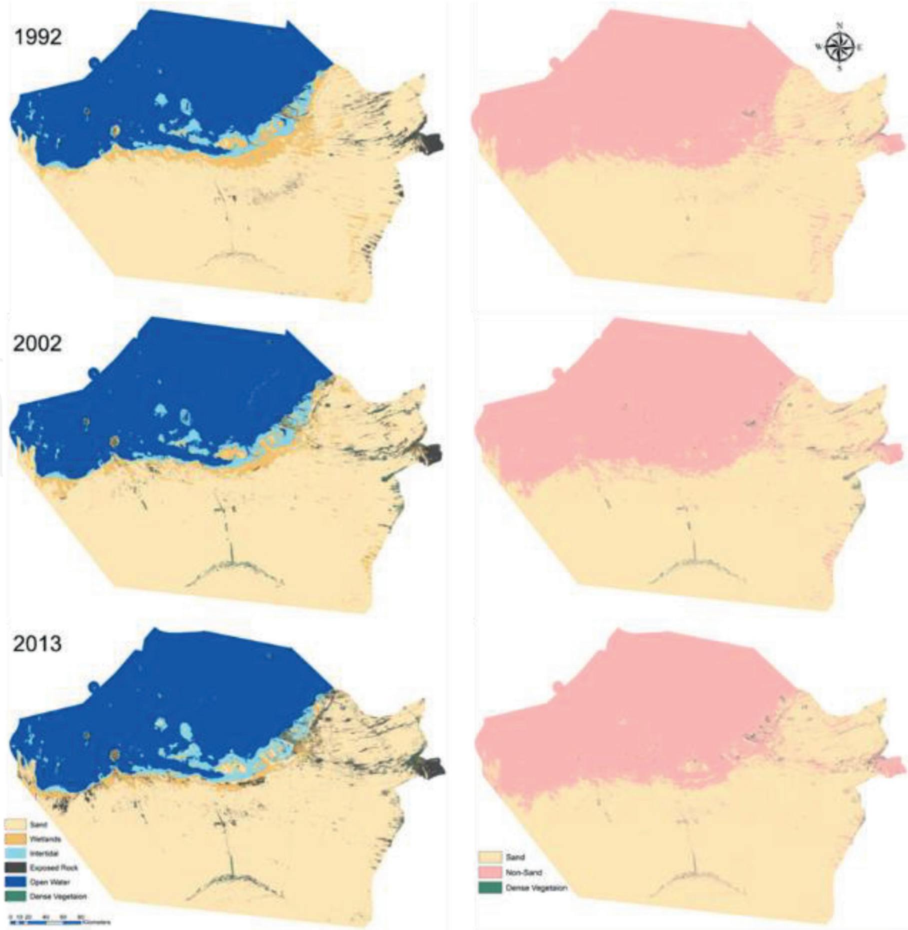

Figure 7.
1992, 2002, and 2013 land cover and sand maps.

Class	1992 (km^2)	2002 (km^2)	2013 (km^2)
Vegetation	147	518	440
Wet soil	5168	4341	2651
Intertidal	3069	2788	3175
Exposed bedrock	1874	1864	3821
Water	32,172	32,873	32,678
Non-sand land	10,258	9511	10,087
Sand	52,186	52,732	52,848

Table 6.
Size of the sand/non-sand classes for 1992, 2002, and 2013.

3.4 GIS-based wind farm site selection model offshore Abu Dhabi Emirate, UAE

The development of turbines that convert wind energy into electrical energy put wind in a good position as a source of alternative renewable energy. This study aims to assess the feasibility of establishing wind farms offshore the Emirate of Abu Dhabi, UAE and to identify favorable sites for such farms using a geographic information system (GIS).

3.4.1 Requirements for wind farm site location

Selecting the appropriate location for a wind farm is a key to its efficiency and success. Considering environmental, legal, and economic conditions, certain locations were found completely inadequate and should be excluded from the selection process, whereas others varied in their degree of suitability. **Table 7** lists the set of conditions that inhibit the siting of a wind farm and lead to the exclusion of areas with these conditions from the selection process. **Table 8** lists the set of criteria that affect the suitability of a location for a wind farm site.

3.4.2 GIS project implementation

Based on the set of criteria discussed in Section 3.4.1, needed datasets were collected, georeferenced to a common spatial frame, and ingested in the project's geodatabase. A GIS model is then built to create an exclusion mask from the input dataset (see **Figure 8**). Areas identified by the model are completely excluded from the selection process.

Areas that are not excluded by the first stage of the model are candidates for wind farms. Their suitability is evaluated using the criteria listed in **Table 8** using a weighted sum overlay approach whose inputs are derived from the wind speed and water depth layers.

The suitability of a location (S) is then calculated from the reclassified inputs using the weighted sum defined in Eq. (2).

$$S = w_{wind} \times \text{ranked wind speed} + w_{depth} \times \text{ranked water depth} \tag{2}$$

where w_{wind} is the weight given to the wind speed criterion and w_{depth} is that given to the water depth criterion.

Given the higher importance of wind in the suitability of a location for wind farming, we assigned a value of 2 to w_{wind} and 1 to w_{depth}. The suitability map resulting from running this model is presented in **Figure 9**. It indicates that only a small fraction of offshore Abu Dhabi Emirate is suitable for wind energy. A substantial

Parameter	Unsuitability condition
Water/land mask	Land
Submarine cables	Within 250 m
Oil and gas wells	Within 250 m
Oil and gas pipelines	Within 250 m
Bird conservation sites	Inside
Environmentally protected areas	Inside
Maritime navigation corridor	Inside

Table 7.
Criteria used to exclude areas from the selection process.

Parameter	Suitability condition
Wind speed	<4.5 m/s: unsuitable 4.5–5.4 m/s: moderately suitable >5.4 m/s: suitable
Water depth	0–10 m: moderately suitable 10–20 m: suitable >20 m: unsuitable

Table 8.
Criteria used to rank non-excluded areas.

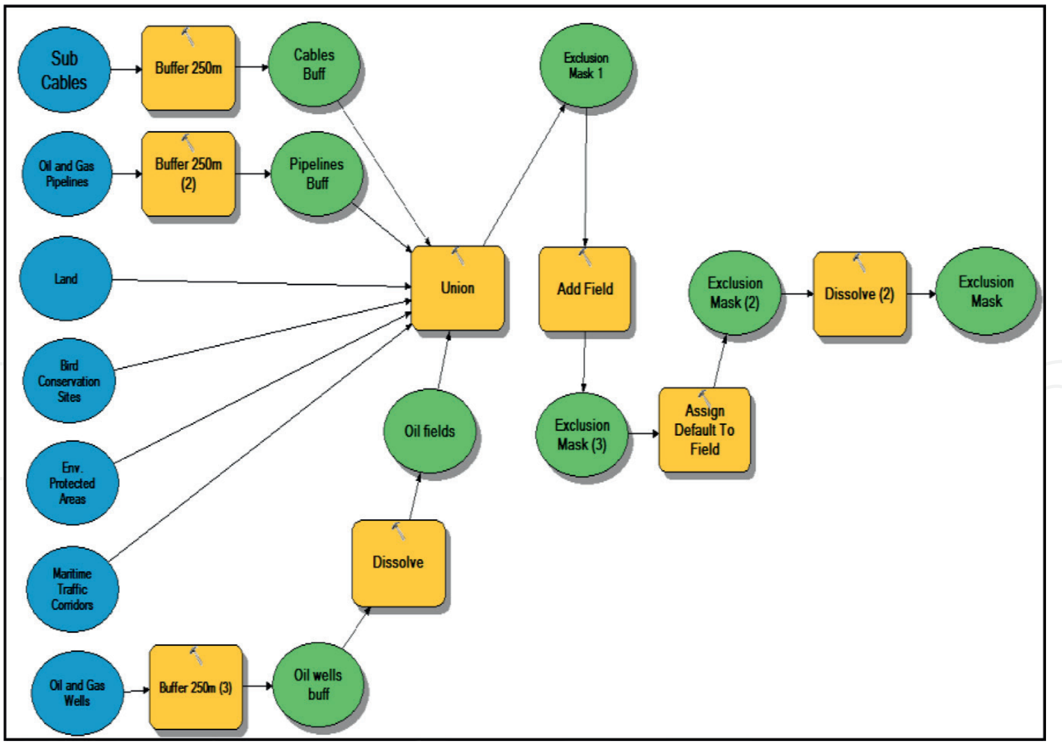

Figure 8.
Diagram of the area exclusion model.

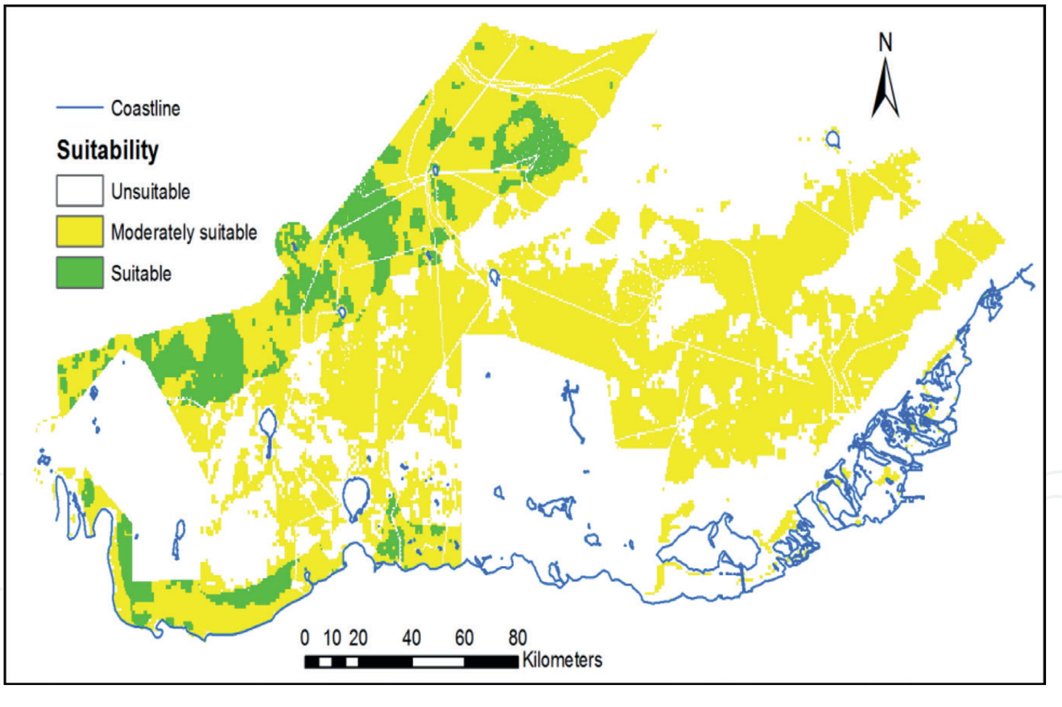

Figure 9.
Final suitability map for wind farm site selection offshore Abu Dhabi.

part of that area is considered moderately suitable. However, some suitable areas are close to mainland and to inhabited islands, such as Delma Island, and can be considered for wind farms to feed these areas.

4. Conclusions

In this chapter we highlighted the importance and outlined some methods of using satellite imagery integrated within GIS to address environmental issues facing human populations living in arid and hyperarid conditions. A systematic approach to use GIS-based models for solving environmental problems was detailed and illustrated in four different case studies to help readers gain better understanding of how GIS was deployed in environmental studies.

Environmental modeling starts with conceptualizing the real world into a mental model which is translated into a logical model implemented using a database management system and then transformed into a physical model to formulate a solution to the issue at hand. Processes and interpretations of the results are then implemented through the use of appropriate data and tools in a GIS environment. Expertise and knowledge to master these techniques will be best ascertained by hands-on practices.

Author details

Salem Issa* and Nazmi Saleous
Departments of Geology and Geography, United Arab Emirates University, Al Ain, UAE

*Address all correspondence to: salem.essa@uaeu.ac.ae

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